Evaluation of Existing Subsurface Drip Irrigation Systems in the Texas Coastal Plains

Project Report

Submitted To:

Texas On-Site Wastewater Treatment Research Council

By:

Andrew N. Ernest, Ph.D., P.E.

Duane Gardner, Ph.D.

Krishna Pavananadan

Alondra Barnes

February 2001

Texas A&M University – Kingsville

Environmental Engineering

Table of Contents

List of Tables

List of Figures

Executive Summary

The primary goal of this research was to evaluate the performance and analyze system failures of on-site subsurface drip irrigation systems, while recommending improvements along with further research studies. The Texas On-Site Wastewater Treatment Research Council funded this study.

Soil type, effluent type and geography were considered in selecting the 18 study sites. Soil and water samples, and other field measurements were taken. Landowners and the county health officials were interviewed to determine the status of on-site systems.

The soil was analyzed for texture, swell shrinkage, bulk density and moisture. The effluent was analyzed for COD, BOD_5, pH, Total Phosphorous, Nitrite and Fecal Coliforms. Effluent flow rates were estimated from the number of occupants or bedrooms. The hydraulic conductivity of the soil at different locations in the drip field was determined through permeability tests.

A multi-regression analysis was carried out to determine the relationships between system failure, loading rate, and other parameters such as soil type, clay content, and swell shrinkage. Clay content ranged from 5-40%, with swell from 0-11%. The minimum pH measured was 6.2, with the maximum being 7.8, while the greatest variation between inlet and outlet pH was 1.2. Removal efficiencies ranged from 23-79% for COD, 0-68% for BOD_5, 62-88% for Total Phosphorous, 77-100% for Total Kjeldahl Nitrogen, and 60-100% for Nitrite, 14-94% for Fecal Coliforms and 90-100% for Total Suspended Solids. Survey information was inconclusive due to insufficient responses. Further study is recommended to assess the potential impact of the accelerated lysimeter protocol used to collect treated effluent, and to develop methodologies to properly characterize the performance of intermittent flow domestic on-site systems.

Objective

Overall Objective

The overall objective of this work was to conduct a performance evaluation of sub-subsurface drip irrigation systems in the Texas coastal areas.

Specific Objective

The specific objectives of this project involved evaluating On-Site Sewage Facilities (OSSF) for different soil types, by concentrating on swelling clay soil, analyzing failure modes and providing recommendations for improvement and further research.

Introduction

Soil has a remarkable capacity to purify wastewater using physical, biological, and chemical processes. In an on-site system, soil filters the wastewater by physically removing solids. Microorganisms in the soil decompose organic compounds, forming biomass, carbon dioxide, and soil organic matter. Soil gasses and the soil itself catalyze chemical transformations that detoxify harmful chemicals (Bicki and Brown 1985).

In the past a conventional septic tank followed by soil trenches was most often chosen for use. This system however often functioned improperly in areas with poor soil, high water tables, excessive slopes, improper installation and distribution problems due to large flows. Proper function requires that neither untreated nor partially treated effluent reaches receiving ground waters or surface waters. It is important to remember that effluent need not reach the surface to indicate failure. A system that permits effluent high in Nitrogen, Phosphorous, or pathogenic microorganisms to reach receiving water bodies is defined to be "functioning improperly" (Tayler, Yahner et al. 1997). Jacquez, Vora et al. (1991) cited a study estimating that upwards of one-half of existing soil absorption systems in the United States did not function adequately. In Nueces county, 20% of OSSF are believed to be failing due to flooding, poor soil conditions and improperly designed systems (Naismith Engineering 1990).

Improper installation often involves improper siting, inadequate absorption area, fractured bedrock, sandy soils (especially in coastal areas), and inadequate soil permeability. It can also include smearing of trench bottoms during construction, compaction of soil beds by heavy equipment and improperly performed percolation tests (Gordon 1989). When analyzing systems in terms of system operation, as many as 75 percent of all system failures have been attributed to hydraulic loading (Jarrett, Fritton et al. 1985). Experience throughout the U.S., with respect to lot size for onsite wastewater disposal, indicates that at least a ¾ acre lot is needed and that a 1- acre lot is more adequate (Perkins 1989).

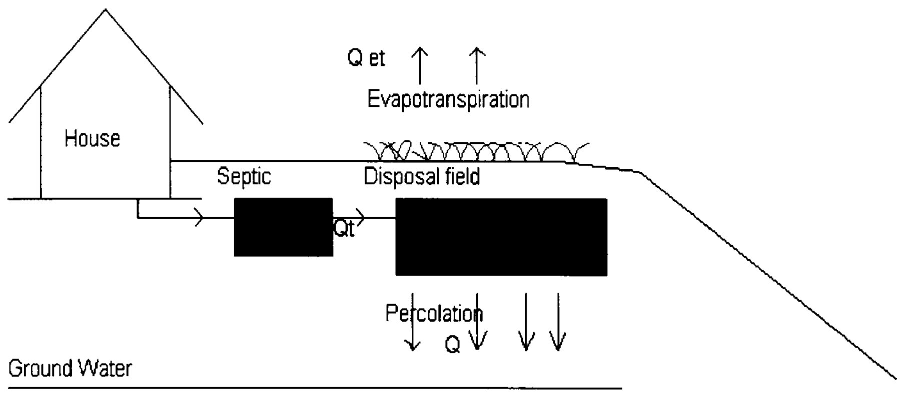
Malfunctioning systems cause undesirable odors, breeding of mosquitoes, ground water pollution, and public health effects. Public and environmental health effects from contamination of water resources have been well documented (EPA 1986). More than 42% of water-associated disease outbreaks have been traced to the consumption of untreated sewage impacted ground water (Keswick and Gerba 1980).

Failing on-site systems generate health concerns beyond water contamination and contact with harmful pathogenic organisms and chemicals, such as Nitrates. They also produce stress on the environment. This may inhibit natural cleansing mechanisms and accentuate health risks of all kinds. Additionally, ponded wastewater from failing on-site systems provides a breeding ground for vector organisms (Mancl and Young. 1997).

Aravena, Evans et al. (1993) showed that nitrification of ammonium is the main process responsible for formation of nitrate. The oxidation of ammonium leads to an increase of nitrate and acidification of ground water.

Background

The most common type of on-site wastewater treatment in Texas area is the conventional septic system as shown in Figure 1, which is composed of a septic tank and drip field. It is estimated that over one-third of the South Texas's population utilize on-site systems for their waste disposal (IUP, 1990).



• Figure 1. Fate of Water Discharged to On-Site Wastewater Treatment System

Alternative on-site wastewater treatment systems such as a sub-surface drip irrigation or trickling systems are installed when conditions are unsuitable (high water table or soil type) for traditional septic systems. Many of the on-site subsurface drip systems are located along the Texas southeast coastal plains as the soils in these areas consist predominantly of swelling clays.

During the three months from June through August of 1999, the Water Quality Research Group at Texas A&M University - Kingsville surveyed the county health departments and Texas Natural Resource Conservation Commission (TNRCC) to determine the status of on-site wastewater disposal in Texas. County environmental sanitarians, permitting authorities, manufacturers, and landowners were polled about the current status of on-site systems.

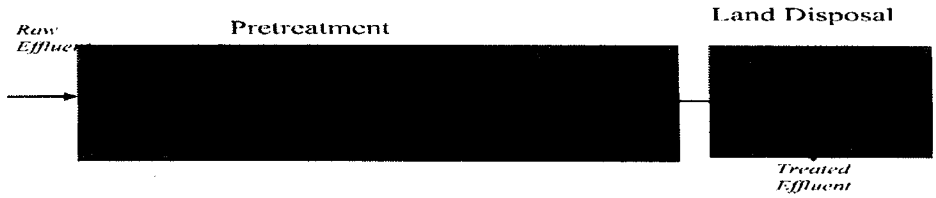
Texas Administrative Code

The Texas Administrative Code 30 chapter 285 (TAC, 1997), defines the framework for site evaluation, planning, construction and maintenance standards for drip irrigation systems. However, enforcement standards for pollutant parameters are not indicated, and the failure of a system must therefore be determined based on the design inadequacies.

The definition of OSSF failure in the Texas Administrative Code (TAC, 1997) is limited to the surfacing of septic water on surroundings or in bathrooms. Landowners are typically unaware of the impact these failures have on ground water pollution. Homeowners are often reluctant to reveal failures for fear of regulatory repercussions.

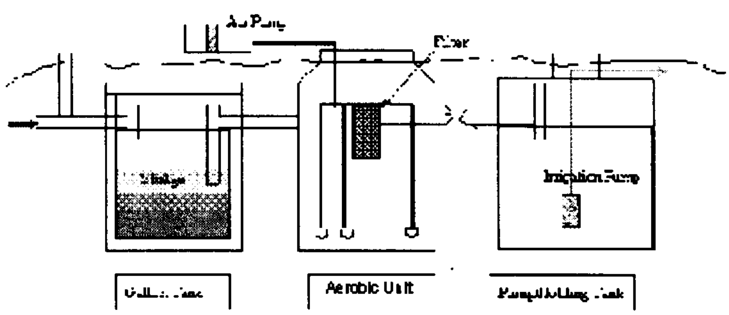
Type of Systems

The most common form of on-site sewage disposal is a septic tank/soil absorption system. A conventional septic system consists of a septic tank, distribution box and a gravel-filled absorption field installed below the soil surface. In an area, where a conventional septic system is unsuitable, alternative or modified systems are installed.

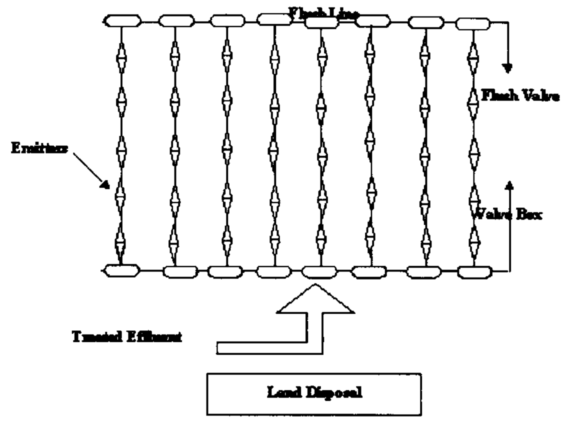


• Figure 2. Subsurface Irrigation Wastewater Treatment

Subsurface irrigation consists of primary treatment, secondary treatment, disinfection and a land disposal system as shown in Figure 2. First, wastewater is passed through an anaerobic settling tank to achieve primary treatment. There, heavy partially decomposed solids known as sludge collect in the bottom of the septic tank, while a scum layer of lightweight material rises to the top. This tank may be compartmentalized to increase the performance. After primary treatment the effluent passes through a secondary treatment aeration system. An aeration system consists of a chamber that mechanically aerates the effluent and decomposes the solids. It is then disinfected using chlorine or ultraviolet radiation. Pretreatments in OSSF include physical and biological processes in the primary and secondary tanks, as well as disinfection (Figure 3). Finally, the treated effluent is dripped into the subsurface soil between 6 to 8 inches below the surface through perforated-tube grid system as shown Figure 4.



• Figure 3. Pretreatment System. Adapted from Hudspeth



• Figure 4. Land Disposal. Adapted from GEOFLOW Inc.

Site Address

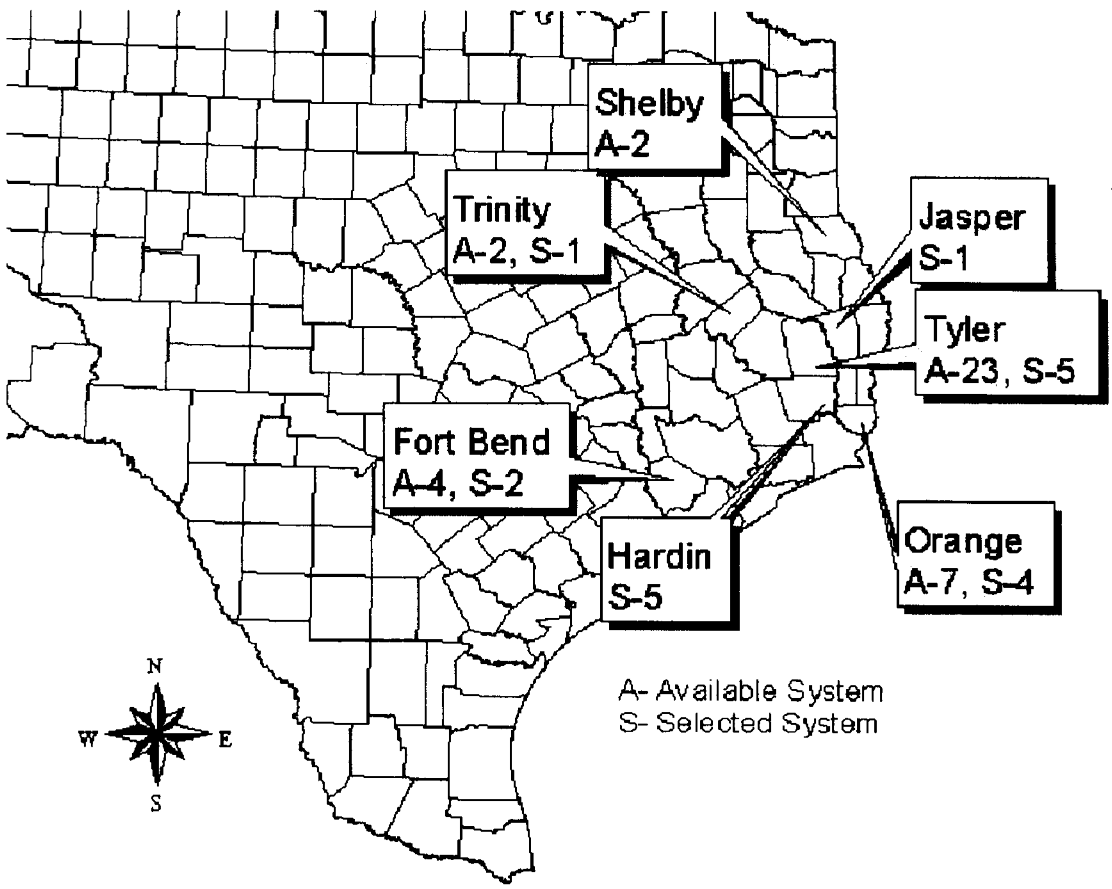
Eighteen sites were visited between June and August of 1999 (Table 1).

• Table 1 Study Sites

Site ID	Date visited	Address	County
1	6/21/99	Mr. Chas Henderson	Orange
2	6/21/99	Mr. Dale Green,	Orange
3	6/22/99	Mr. Barry Murchiso,	Orange
4	6/23/99	Mr. David Gallegos	Orange
5	6/30/99	Mr. McNeil Johnson	Tyler
6	6/31/99	Mr. Tom Holland	Hardin
7	7/1/99	Mr. Roy Ryan	Tyler
8	7/23/99	Mr. Robert Forsyth	Tyler
9	7/20/99	Landmark Industries	Fortbend
10	7/21/99	Mr. Herbert Black	Hardin
11	7/21/99	Mr. Jay Dippel	Tyler
12	7/22/99	Mr. Harold Bruce	Jasper
13	7/22/99	Mr. Joe Chaney	Hardin
14	7/23/99	Saratoga Post Office	Hardin
15	8/21/99	Mr. Sander	Trinity
16	8/21/99	Mr. Miller	Tyler
17	8/21/99	Mr. Jordan Jack	Hardin
18	8/22/99	Gas Station	Fortbend

Site map

Figure 5 depicts the counties evaluated during the screening phase of this work. Table 2 lists the numbers of available selected sites in the counties visited.



• Figure 5. Texas Coastal Plains by County

• Table 2. Visited Sites - By County

County	Available systems	Selected
Orange	7	4
Tyler	23	5
Fort bend	4	2
Shelby	2	-
Trinity	2	1
Jasper	-	1
Hardin	-	5

Manufacturers Data

The manufacturers or installers of the selected systems are given in Table 3.

• Table 3. Visited Sites - Manufacturers or Installers.

Manufacturer/Installer	No of systems
Professional Eng service	1
Multi Flow	2
Eastex	1
Bosco construction	2

Manufacturer/Installer	No of systems
Nowesco	1
ClearStream	11

Failure Definition

Failure may be caused during one or more of three phases:

1. Design
2. Installation
3. Maintenance/Operation

A proper design usually encompasses environmental factors such as site evaluation (climatic, topographical and soil conditions), type of use (residential, commercial strength of waste) and hydraulic loading rate. For a successful onsite system a competent installation is also necessary. The third phase is more difficult to execute, because it requires the skill necessary to monitor and maintain a variety of systems. This is particularly true in aerobic systems. The research group categorized system failure into four classes, based on inspection.

Class A - Raw Sewage on the Bathroom Floor

This failure faced by owners occurs when raw sewage is rejected by the disposal system. Clogging of pipes in the septic tank, solid build up in the septic tank and failure of pipelines cause this type of failure. The owner usually easily identifies this type of failure.

Class B - Sewage in the Yard

In this type of failure, called hydraulic failure, the system seems to function properly, but untreated or poorly treated sewage surfaces in the yard, nearby ditches and neighboring yards. Of the 18 sites, only one site had this type of failure, where the water was emerging from the drip system and flowing into a nearby ditch. The probable reason for this site failure was high water levels (due to a rainy day) and the system's proximity to the ditch (<2 ft). Class B types of failures are mainly due to high seasonal water table levels.

Class C - Decline in Water Quality

In this case the household plumbing and drain field seem to be working perfectly. There is no odor in the vicinity of the system and no excess wetness around the drain field. However, the effluent percolating from the drip system reaches the ground water and/or surface water without having received adequate treatment. This type of failure can be identified by monitoring ground water quality and is difficult for owners to detect. The reason for this type of failure is mainly due to poor selection of design parameters or organic and hydraulic overloading. Class C types of failures are mainly dependent on the size of the unsaturated zone in the soil.

Class D - Long Term, Gradual, Environmental Degradation

This type of failure occurs when the soil exhausts it purification capacity. Long term monitoring and modeling is necessary to predict this type of failure.

Of the four types of failure, our studies concentrated on Class B, and Class C type failures, since our objective was evaluation of performance of subsurface irrigation systems.

It was difficult to estimate the number of failures, because most of the house owners and manufacturers were reluctant to reveal such information.

Class B failures are caused by:

1. **Higher level of ground water**. To prevent a Class B failure the septic system must be designed such that an unsaturated zone will exist beneath the drain field even during the wet season. Normally the investigator does not have a detailed record of water table fluctuation for a site. Therefore the depth of wet season water table should be estimated from a combination of factors that relate to soil wetness including climatic conditions, landscape, and soil morphology.

2. **Clogging of soils**. Clogging of soils occurs when the water can't percolate very fast due to tight soils (the soil surface becomes too compacted during construction), clogged infiltrate surface (because of overloading of suspended solids), and the formation of a biomat at the interface of soil and swelling clay.

Monitoring the ground water for effluent quality over a long period of time can determine a Class C type failure. This type of failure is evident if the final effluent quality as measured by COD, BOD_5, TSS, Fecal Coliforms etc., surpasses the standards. This failure is further analyzed with respect to loading rate and soil properties.

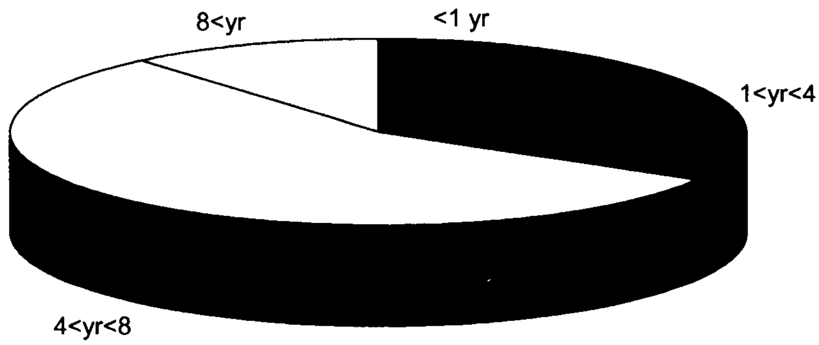
A Class C type failure of the system occurs when the percolated effluent parameters (EP) surpass standard parameters (ESP) {EP>ESP}

Material And Methods

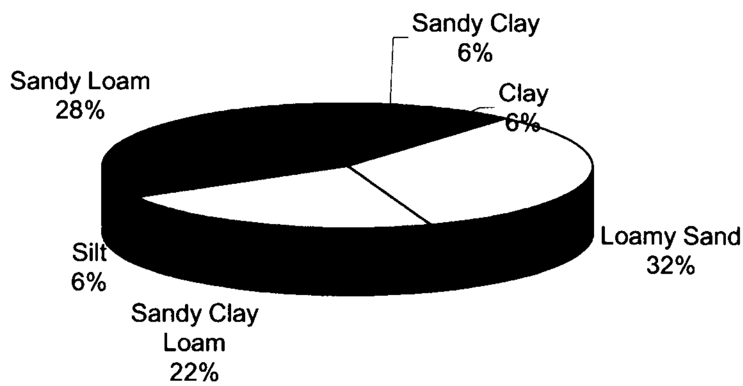
Site, System Selection

This project focuses on the evaluation of performance of OSSF for clay soils. All systems were reviewed to screen eighteen sites that would give better findings that accommodated different scenarios such a soil type, system age, type of effluent and topographical conditions. This study concentrated on sites with clay soils.

The age of system, soil type selected and type of effluent are shown in Figure 6, Figure 7 and Table 4.



• Figure 6. Visited Sites - System Age



• Figure 7. Visited Sites - Soil Types

• Table 4. Selected Site Effluent Types

Type of effluent	No of system
Domestic wastewater	15
Post Office	1
Service Station	2

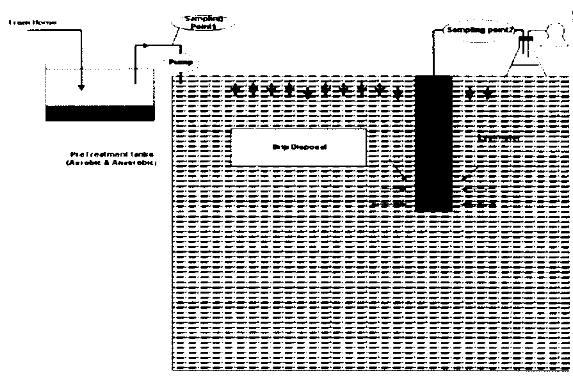
Sample Collection

Raw effluent samples were collected from the pump tank of the septic system. The treated effluent sample was collected using a lysimeter. The lysimeter was inserted underground to a 6-ft depth (See Figure 8) into a 6 inch diameter borehole. The borehole allowed for a 1.5-inch thickness of silica slurry around the porous filter of the lysimeter. Then the lysimeter was activated and a vacuum pressure of 15 psi was maintained. The first one-third-sample volume was eliminated and then one liter of treated sample was collected. The sample was preserved in ice to avoid degradation during transport to lab for analysis. The soil samples were collected at 1, 2 & 3-foot depth using a 6 inch diameter hand auger.

Standard operation of the lysimeter requires a vacuum of 15 psi to be applied to the Soil Water Sampler. The collection period depends on soil type. In loams and clay loams, collection of 300 to 500 ml of effluent takes over a period of a day with applied vacuum of 2 psi, when soils are at field capacity (SME Corp. 1999). Equilibration times vary according to soil type and hydraulic conductivity. Wilson (1995) suggests and equilibration times in excess of a year prior to sample collection, while EPA (1998) recommends a minimum of 2 weeks to a month. Due to project time constraints, this time period had to be reduced significantly while meeting all the other recommendation as per the lysimeter operation protocol (SME Corp. 1999). Other relevant limitations of the use of suction samplers include the following (Wilson 1995):

- A sufficient sample volume may be difficult to obtain.
- The time necessary to extract a sample may exceed sample holding times.
- Upwards of 100 samples may be required to obtain a 70% confidence level.

Inadequate equilibration of the lysimeter with its surrounding could result in a carry-over of vertical cross contamination between the raw and treated effluent occurring during the excavation of the hole, resulting in higher than ambient concentrations being measured at the instrument depth. An equally likely scenario is the measurement of lower than ambient concentrations being measured due to dilution by the slurry water.



• Figure 8. Collection of Effluent Sample Using a Lysimeter

Field Measurements

The Model 2800K1 Guelph Permeameter (Figure 9) is a constant-head device, which operates on the Mariotte siphon principal used to determine hydraulic conductivity, matrix flux potential and soil sorptivity in the field (SME Corp.). Water head of 10 and 5 cm was maintained with well depth of 15 cm. The hydraulic conductivity measurements were taken close to (< 1 m away from) the location where samples for soil analysis were taken. Two measurements were taken per drip field.

• Figure 9. Guelph Permeameter

Sample Analysis

The soil samples were analyzed for soil moisture, soil texture and swell shrinkage following ASTM Standard Methods.

The water samples were analyzed for pH, COD, BOD_5, Fecal Coliforms, Total Kjeldahl Nitrogen (TKN), Nitrite, TSS and Total phosphorus. APHA standard was used for water sample analysis (APHA 1995). An adequate chemical inventory was not available for Nitrate analyses at the start of the project, which, due to a series of internal miscommunications, resulted in the entire Nitrate analyses being eliminated from the implemented workplan.

Organics and Solids

Organics are commonly measured as BOD_5 (the 5-day Biochemical Oxygen Demand), which indicates the presence of both readily degradable soluble organics and particulate organic matter. COD (Chemical Oxygen Demand) can be used to analyze the failure below. COD values are generally higher than the BOD_5 because more compounds can be chemically oxidized than can be biologically oxidized. COD measurements can be determined in three hours compared to the 5-day BOD measurement and are less prone to the effects of sample holding times.

It is recommended that analysis of BOD samples should begin within six hours of collection (APHA 1995). The maximum allowable time limit to carry out any BOD test is 24 hours after the sample collection. The recommended procedure for storage in such cases where there is a significant time lag between the storage of the samples and their analysis is to keep the sample at or below 4^0C from the time of collection. Even at low temperatures, the holding time is to be kept to a minimum. The chilled samples were warmed to 20^0 C before analysis.

Due to the sampling campaign being carried out in 18 different locations, most of which were distant from the labs at which the analysis was to be carried out, the analysis of the samples within a period of six hours was not always possible. In some cases, the time lag between the sample collection and analysis was close to 24 hours. In all cases, the recommended procedure of sample storage as described above was followed.

In cases where sample holding times approached the acceptable limits, resulting in questionable BOD_5 measurements, BOD_5 values are estimated based on the COD values, using the ratio calculated from the acceptable BOD_5/COD ratio. The COD test is not a direct substitute for BOD test; however the ratio can be correlated. This requires COD vs BOD testing for number of samples over period of time and its applicability is questionable for separate and discrete waste streams regardless. For typical untreated domestic wastes, however BOD_5/COD ratio varies from 0.4 to 0.8 (Metcalf & Eddy 1995).

The Treated effluent parameters depend on:

1. Soil type
2. Clay content
3. Swell shrinkage
4. Effluent loading rate
5. Climatic, soil and biological conditions.

Effluent loading and COD value can be combined into a single parameter called COD loading rate (Kg COD/m^3.d).

Phosphorous

Reneau, Hagedorn et al. (1989) list the mechanisms for removing phosphorus from effluent water in the soil system to include plant uptake, biological immobilization, and adsorption processes. Clay and organic fractions of the soil provide sorption sites. Therefore, sandy soils typically have lower capacities than clayed soils. The removal process typically starts with fast sorption reaction, followed by slower immobilization due to the solubility precipitates. Soil has greater capacity for retention of phosphorous than is predicted by adsorption theories, since sites "regenerate" as precipitation proceeds (Tyler, Laak et al. 1977).

Nitrogen

Of all pollutants in domestic wastewater, perhaps the most problematic is nitrogen. Typically, the majority of the nitrogen in septic tank effluent is in the form of ammonium. In properly functioning disposal systems, unsaturated (aerobic) conditions should predominate beneath the trench. Much of this ammonium will be nitrified (converted to the nitrate form) in the soil surrounding the trench. Unless conditions are favorable for denitrification, nitrate is not readily removed from the percolating water, resulting in the potential for nitrate pollution of receiving waters (Laak 1982; Petrovic 1990).

Adsorption can theoretically remove large quantities of ammonium from solution, assuming that the cation exchange capacity of the soil is sufficiently high. However, ammonium must persist for a sufficient length of time in order for significant adsorption to occur under anaerobic conditions, since it is readily nitrified under aerobic conditions.

Bacterial and Viral Pathogens

Septic tank effluent can contain significant numbers of pathogens typically 10,000 pathogenic viruses/L. When septic effluent moves through the soils for a sufficient period of time bacteria and viruses are likely to be removed by straining, adsorption, and die off. If the absorption field is very close to a high water table, permeable sand and gravel, or fractured rock; adequate sewage attenuation may not occur, allowing microorganisms to enter the groundwater. Physical straining (filtration) limits the travel of bacteria, so bacterial removal efficiency is typically inversely proportional to soil particle size (Canter and Knox 1985). Hagedorn, McCoy et al. (1981), reports on studies that show reduction of bacterial levels in septic tank effluent to those obtained from "control" soil samples within 61 cm (2 feet) of trench bottoms. The bacterial indicator used to analyze septic effluent and treated effluent is fecal coliforms.

Since viruses are extremely small, the primary removal mechanism in any type of soil is adsorption (Gerba and Goyal 1985). Further, Frankenberger states: "Virus removal from percolating wastewater is almost totally dependent on adsorption to various soil components" (Frankenberger 1988).

Effluent Quantification

The effluent was quantified based on the pumping capacity and the number of bedrooms in a household. The correlation between the number of bedrooms and water quantity was used.

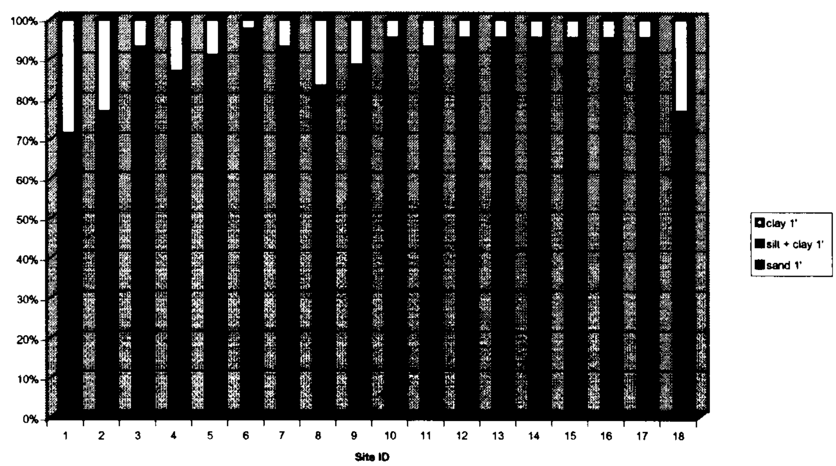
Quality Assurance Methods

American Public Health Association (APHA 1995) methods for sample collection, preservation, and handling of wastewater were followed. Samples were collected in duplicate and preserved in ice. Sample analysis was conducted on duplicates and blanks. Check samples were used to evaluate the precision of both sampling and laboratory procedures. All possible measures were taken to prevent analytical errors.

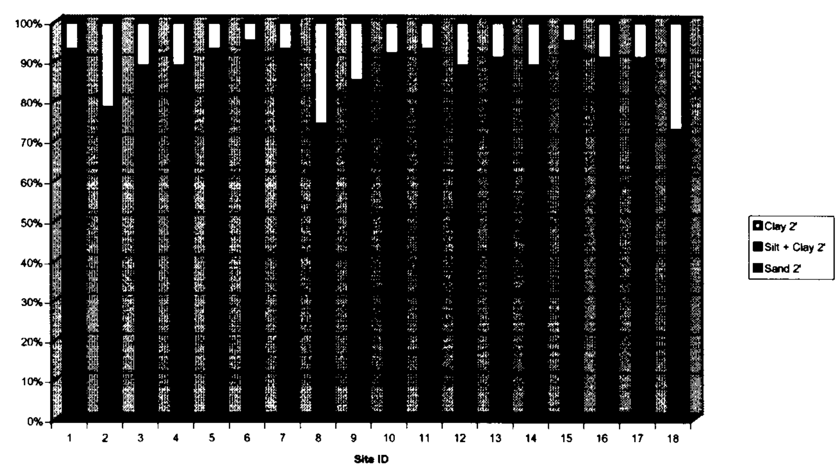
Results

Soil Characterization

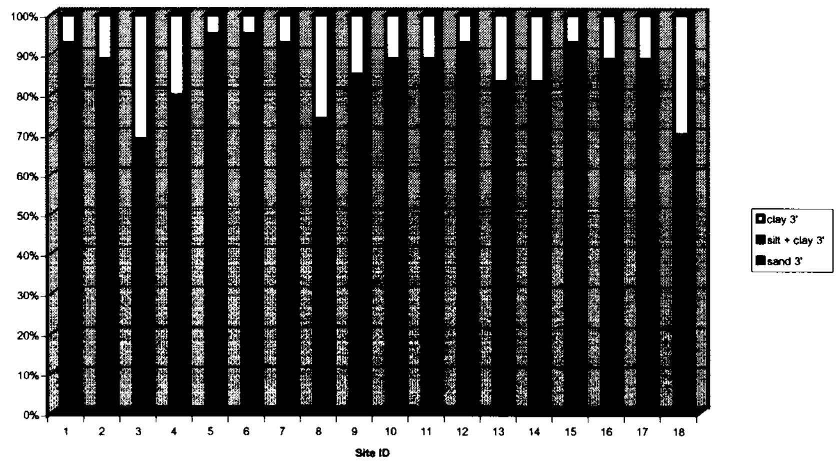
The results of soil texture and moisture characterization are given in Figure 10 through Figure 13.



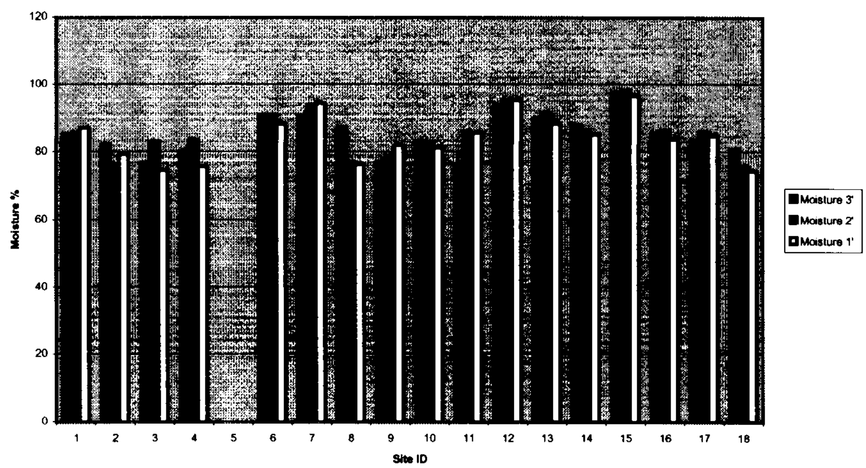
• Figure 10. Soil Texture at 1ft.



• Figure 11. Soil Texture at 2ft.

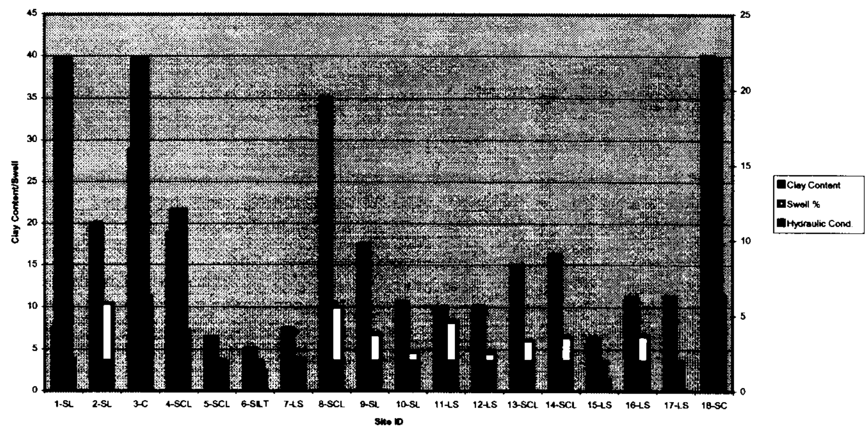


• Figure 12. Soil Texture at 3ft.



• Figure 13. Soil Moisture at Depth.

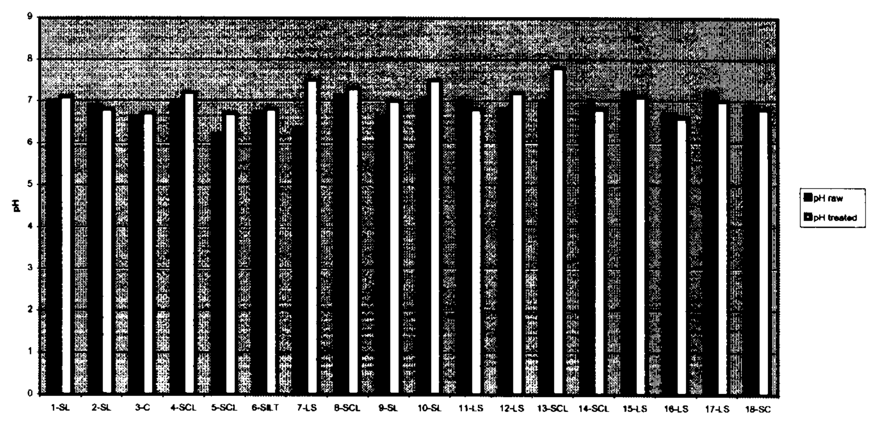
Soil clay content varied from 5 to 40, with a mean value of 15.4. Swell shrinkage varied from 0.2 to 11.4%, with a mean value of 6.1%. Various soil types were found, ranging from Sandy Loam (SL), Sandy Clay (SC), Clay (C), Loamy Sand (LS), Sandy Clay Loam (SCL), to Silt. Hydraulic Conductivity ranged for 2 to 22 mm/min, with a mean value of 5.9 mm/min.



• Figure 14. Soil Clay Content (%), Swell Shrinkage (%) & Hydraulic Conductivity (mm/min).

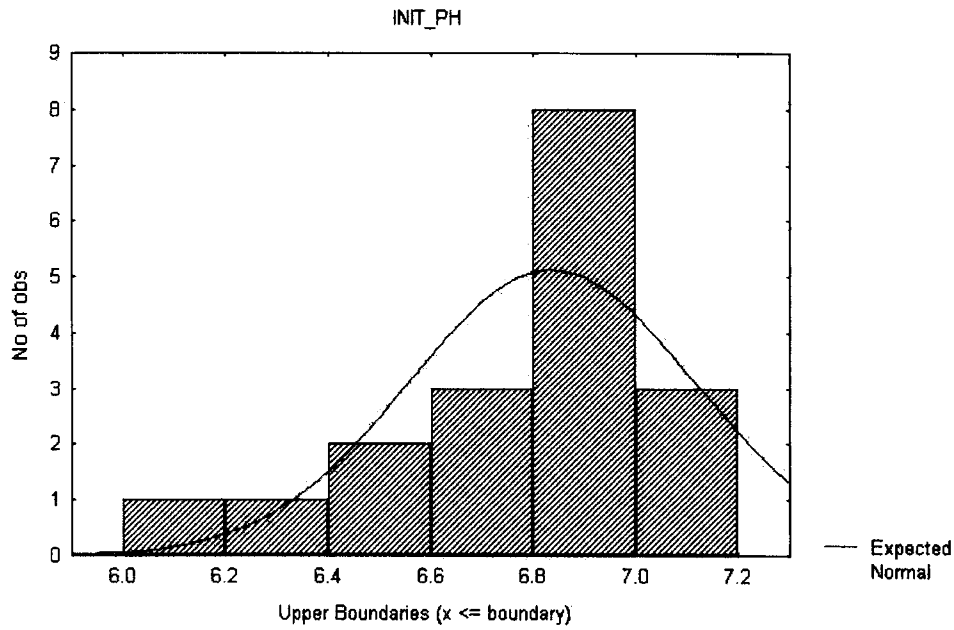
pH

The pH of the raw and treated effluent ranged between 6.2 to 7.8, with a mean value of 6.9. The variability between raw and treated effluent pH ranged between 0.1 and 1.2, with a mean range of 0.3.

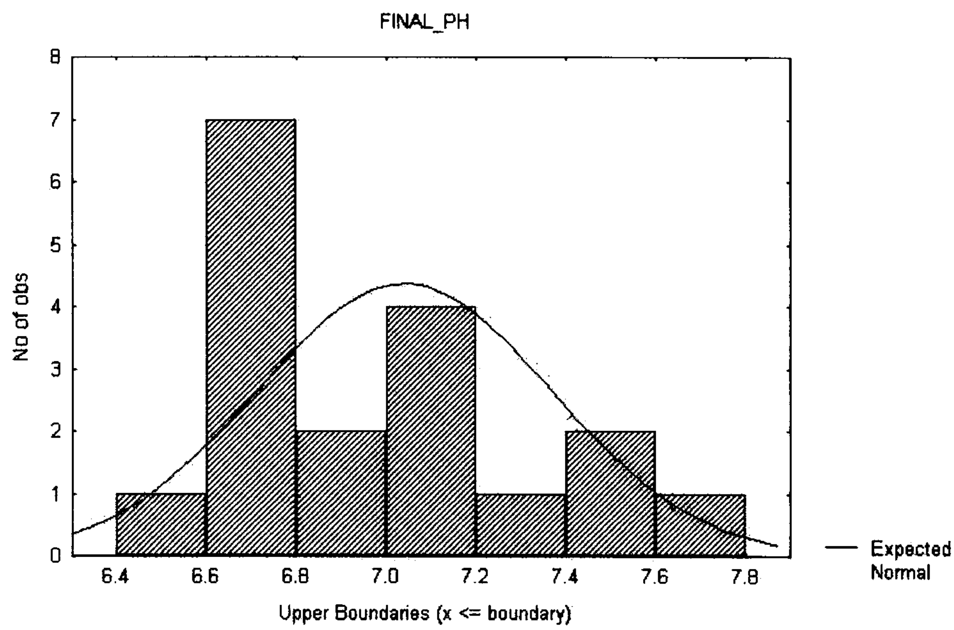


• Figure 15. Raw & Treated Effluent pH

Incidence analysis of the raw and treated effluent pH indicates a slight decrease in pH through the treatment process (Figure 16 and Figure 17), while the distribution of pH tends to be normal.



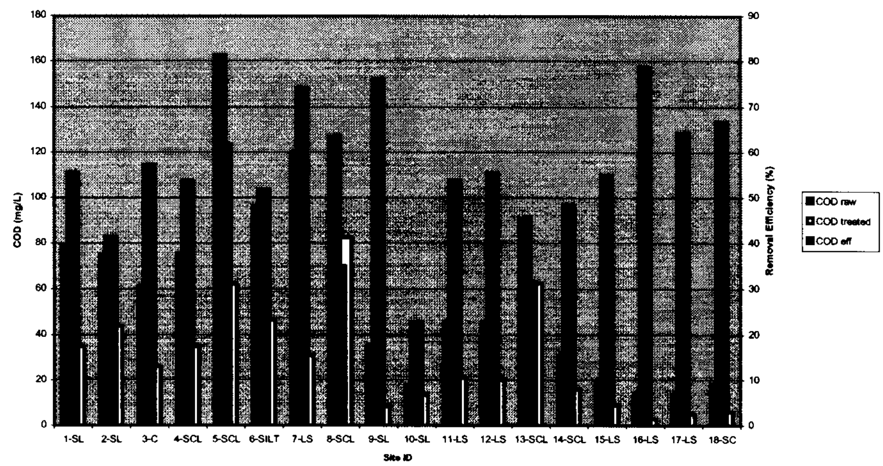
• Figure 16. Raw Effluent pH Incidence



• Figure 17. Treated Effluent pH Incidence

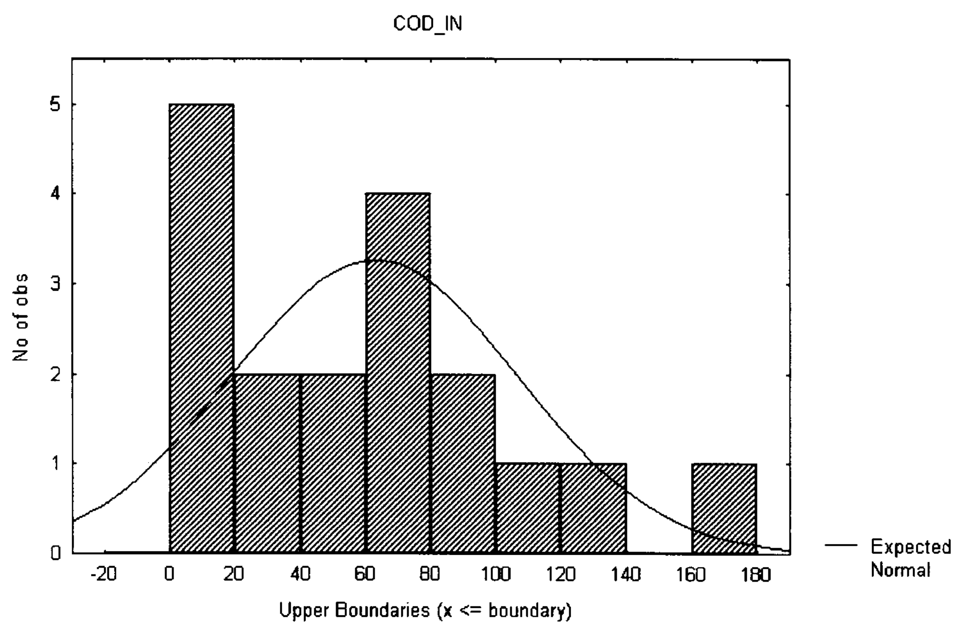
Chemical Oxygen Demand

The COD of the raw effluent ranged between 14 to 163 mg/L, with a mean value of 63 mg/L. The COD of the treated effluent ranged between 3 to 83 mg/L, with a mean value of 29 mg/L. The COD removal efficiency ranged between 23 to 79%, with a mean of 55%.

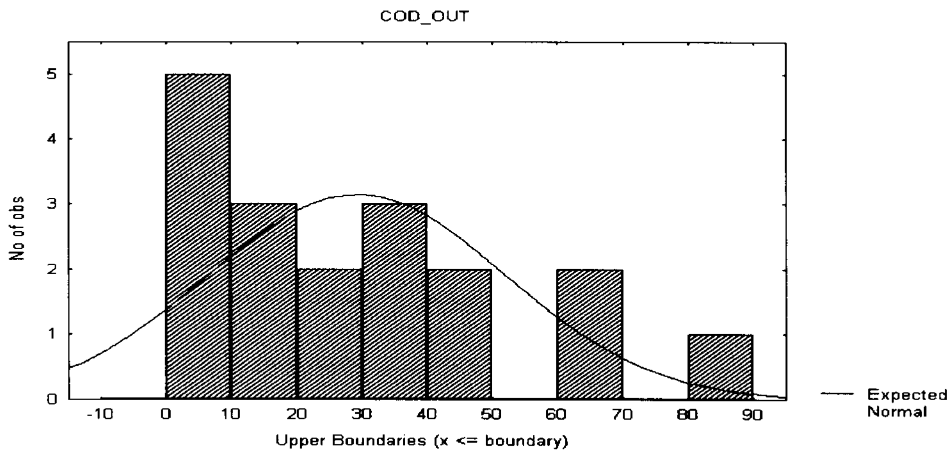


• Figure 18. Raw & Treated Effluent COD.

An incidence analysis of COD appearing in the raw and treated samples is shown in Figure 19 and Figure 20. Both raw and treated COD sample distributions tend to be negatively skewed.



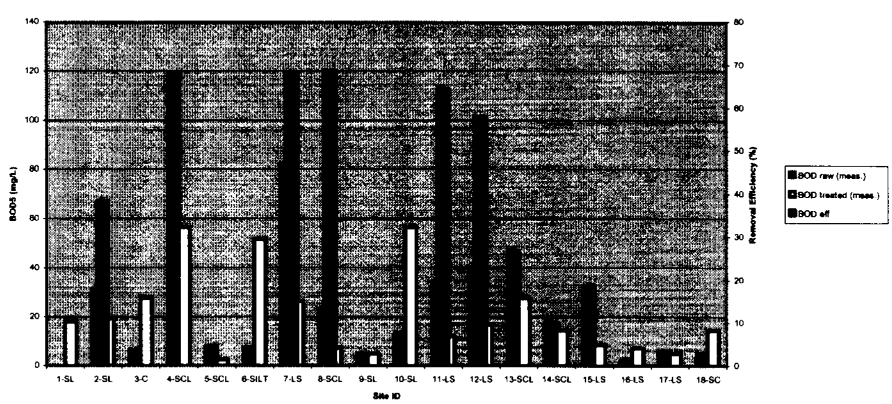
• Figure 19. Raw Effluent COD Incidence



• Figure 20. Treated Effluent COD Incidence

Biochemical Oxygen Demand

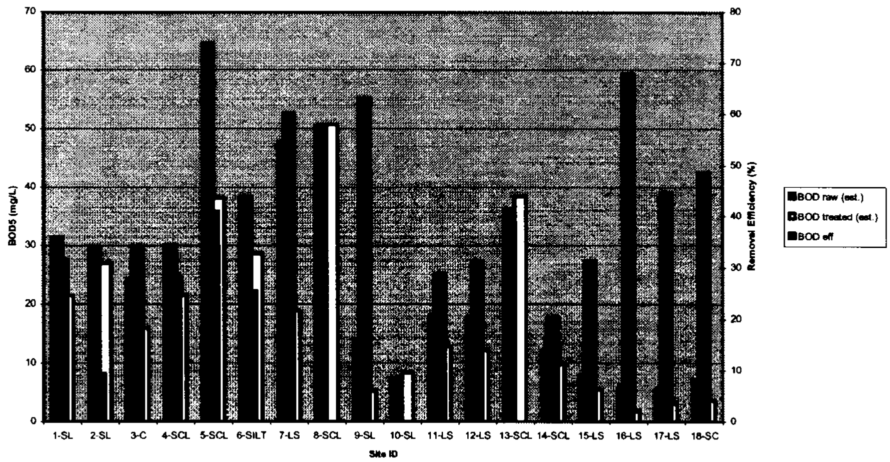
The measured BOD_5 of the raw effluent ranged between 0 to 119 mg/L, with a mean value of 27 mg/L. The measured BOD_5 of the treated effluent ranged between 2 to 56 mg/L, with a mean value of 21 mg/L. The BOD_5 removal efficiency ranged between 0 to 68%, with a mean of 49%. Only measured BOD_5 data from sites 2, 7, 8, 9, 11 and 14 were considered in the estimation of removal efficiencies (Figure 21). BOD_5 from all other sites we deemed inconsistent, with the rationale expressed in Table 14 in the Appendix.



• Figure 21. Raw & Treated Measured Effluent BOD_5.

BOD_5 measurements proved to be the most troublesome due to great variability in the results attributed to sample holding time issues. In an attempt to correct for analytical inconsistencies in the measured BOD_5 values, estimates were made from COD values using ratio of consistent BOD_5 and COD data. The average BOD_5/COD ratio for raw effluent is 0.4 while that for the treated effluent is 0.6.

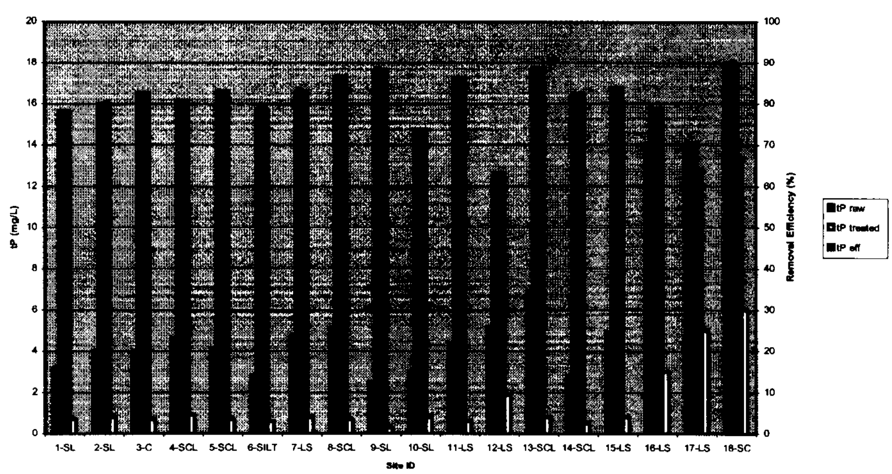
The estimated BOD_5 of the raw effluent ranged between 5.6 to 65 mg/L, with a mean value of 25 mg/L. The estimated BOD_5 of the treated effluent ranged between 2 to 51 mg/L, with a mean value of 18 mg/L. The BOD_5 removal efficiency ranged between 0 to 68%, with a mean of 35%. Estimated BOD_5 data from sites 10 and 13 were not considered in the estimation of removal efficiencies (Figure 21).



• Figure 22. Raw & Treated Estimated Effluent BOD_5.

Phosphorous

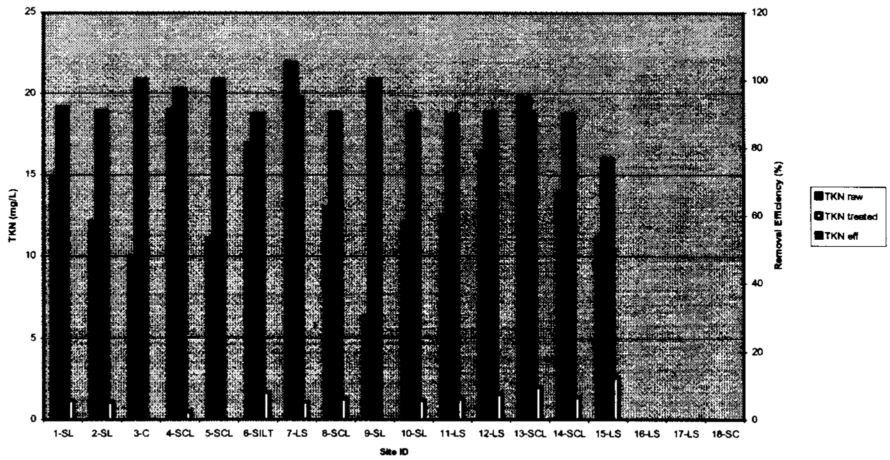
The Total Phosphorous content of the raw effluent ranged between 2.5 to 18 mg/L, with a mean value of 6 mg/L. The Total Phosphorous content of the treated effluent ranged between 0.3 to 6.0 mg/L, with a mean value of 1.4 mg/L. The Total Phosphorous content removal efficiency ranged between 62 to 88%, with a mean of 79% (Figure 23).



• Figure 23. Raw & Treated Effluent Phosphorous.

Total Kjeldahl Nitrogen

The Total Kjeldahl Nitrogen content of the raw effluent ranged between 6.3 to 21.9 mg/L, with a mean value of 14.1 mg/L. The TKN content of the treated effluent ranged between 0.to 2.6 mg/L, with a mean value of 1.1 mg/L. The TKN content removal efficiency ranged between 77 to 100%, with a mean of 92% (Figure 23).



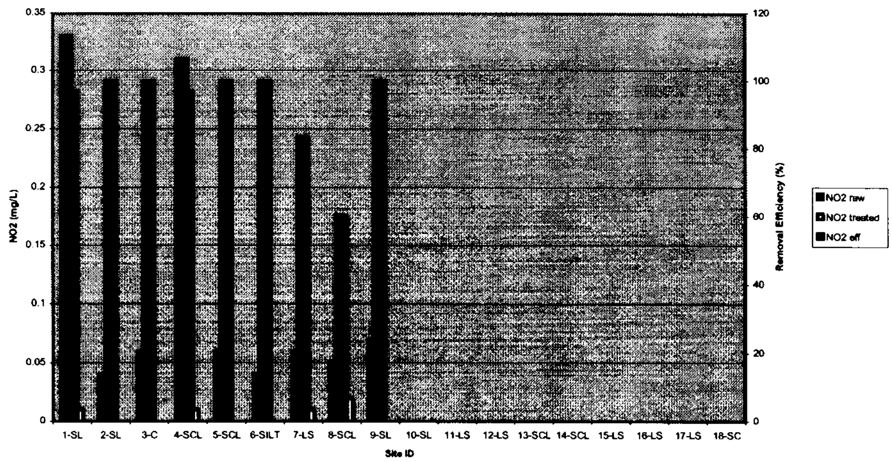
• Figure 24. Raw & Treated Effluent Total Kjeldahl Nitrogen.

Nitrate

Nitrate analyses were not conducted on the samples due to laboratory chemical delivery problems.

Nitrite

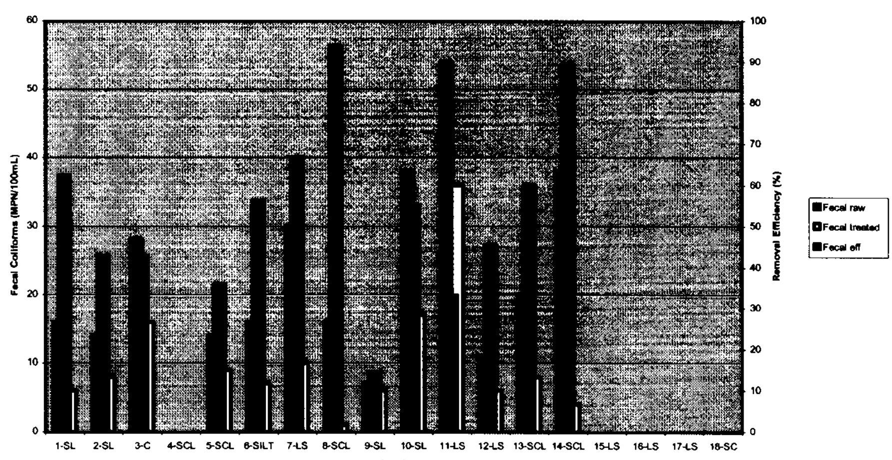
The Nitrite content of the raw effluent ranged between 0.04 to 0.33 mg/L, with a mean value of 0.11 mg/L. The Nitrite content of the treated effluent ranged between 0 to 0.02 mg/L, with a mean value of 0.01 mg/L. The Nitrite removal efficiency ranged between 60 to 100%, with a mean of 93% (Figure 25). Only data from Sites 1-9 were used in the estimation of removal efficiency. Nitrite data from Sites 10-14 demonstrated values dramatically inconsistent with Sites 1-9 and orders of magnitude greater than the generally accepted range. These Sites were not included in the Nitrite analysis. Nitrite analysis was discontinued for Sites 16-18.



• Figure 25. Raw & Treated Effluent Nitrite.

Fecal Coliforms

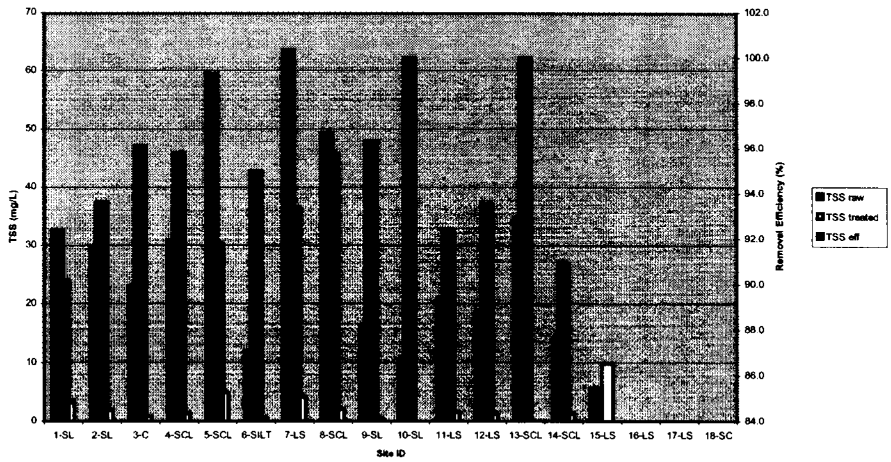
The Fecal Coliform content of the raw effluent ranged between 7 to 54 MPN/100mL, with a mean value of 23 MPN/100mL. The Fecal Coliform content of the treated effluent ranged between 1 to 36 MPN/100mL, with a mean value of 10 MPN/100mL. The Fecal Coliform removal efficiency ranged between 14 to 94%, with a mean of 54% (Figure 25).



• Figure 26. Raw & Treated Effluent Fecal Coliforms.

Total Suspended Solids

The Total Suspended Solids load of the raw effluent ranged between 6 to 64 mg/L, with a mean value of 28 mg/L. The TSS load of the treated effluent ranged between 0 to 10 mg/L, with a mean value of 2 mg/L. The TSS removal efficiency ranged between 90 to 100%, with a mean of 95% (Figure 25).



• Figure 27. Raw & Treated Effluent Total Suspended Solids.

Discussion

Neglecting climatic conditions, correlation analysis between swell, clay %, COD loading and COD outlet gives the results in Table 5.

• Table 5. Correlation analysis Swell, Clay%, COD Loading rate and COD Outlet value

	Swell	Clay %	COD loading	COD out
Swell	1.000	0.824	-0.202	0.144
Clay %	0.824	1.000	-0.269	0.121
COD load	-0.202	-0.269	1.000	0.357
COD out	0.144	0.121	0.357	1.000

The COD loading appears to influences the quality of the treated effluent more (0.357) than Clay content (0.121) or swell-shrinkage (0.144) .

Further using multiple regression analysis with Statistica® (Stat Soft 1998) software the COD (mg/l) at the outlet is determined by:

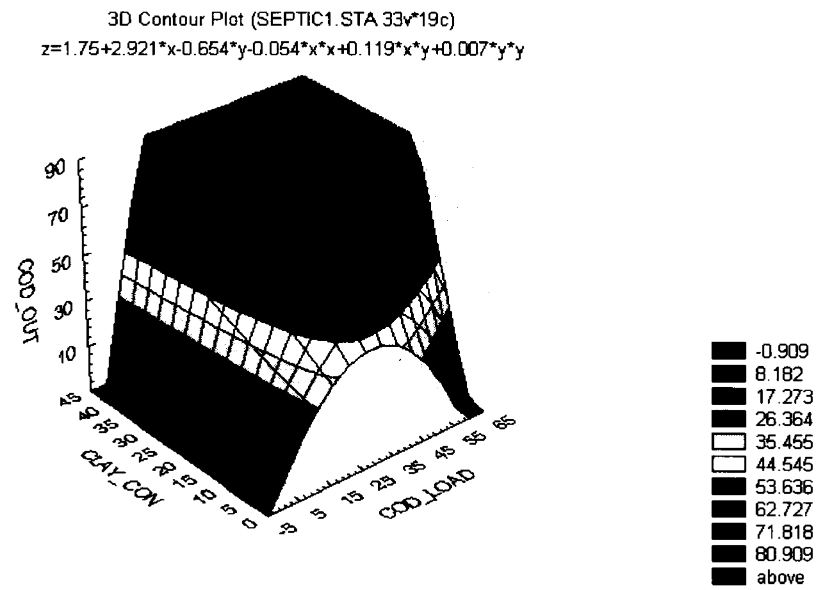
• Equation 1 COD at Outlet – Multiple Regression Analysis

$$Z = 1.75+2.921X-0.654Y -0.054X^2+0.119XY+0.007Y^2$$

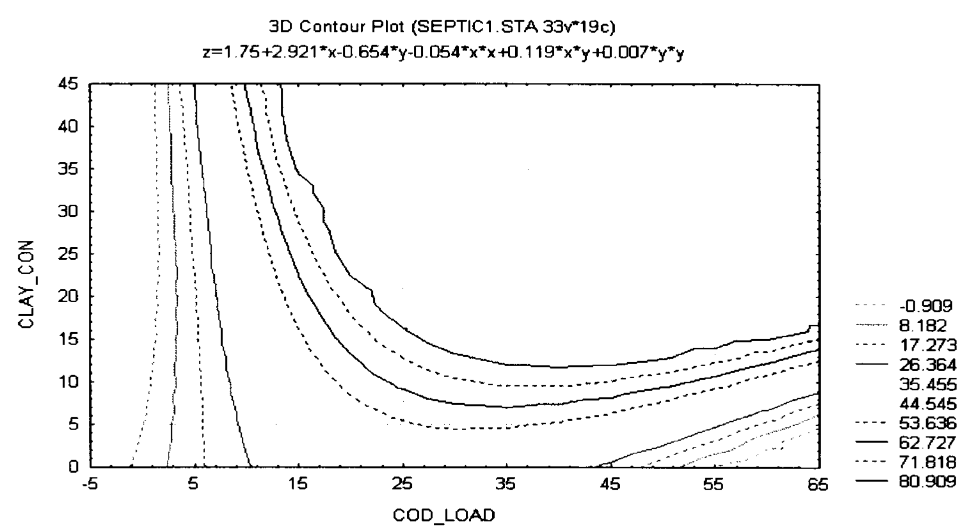
Where

Z = COD (mg/l)
Y = COD loading (kg COD/m^3/day)
X = Clay content (%)

Figure 28 shows a 3D plot of COD loading vs. clay %, vs. COD outlet. This shows that the amount of COD in the treated effluent in onsite treatment system increases with COD loading and clay content. It is therefore easy to roughly predict the failure based on clay content and loading using this graph or Equation 1. However this needs to be refined incorporating other factors such as climate conditions, soil porosity, etc.



• Figure 28. COD Loading Vs Clay % Vs COD outlet



• Figure 29. COD Loading Vs Clay % Vs COD Outlet

Measured BOD_5 and COD removal efficiencies were lower (0-68% and 23-79%) than expected values when compared to slow-rate (98-100%) and rapid-infiltration (75-100%) systems (Metcalf & Eddy 1995; Crites and Tchobanoglous 1998). However, it should be noted that, the slow-rate and rapid-infiltration systems cited most frequently are for large flows (millions of gallons per day) and loading rates (tens of lb/ac*d of BOD), whereas flow rates for domestic on-site systems is are intermittent (gallons per day, with frequent no-flow conditions) and organic loading rates for these systems are less than 0.2 lbs/ac*d of BOD). Domestic on-site systems therefore have the greatest potential for performance variability. Low loading rates and intermittent flows are anticipated to have a diminishing effect on removal efficiencies for organic matter. Limited work has been done on characterizing the performance of small single-family systems.

Conclusions

- Removal efficiencies of the evaluated drip systems were: 23-79% for COD, 0-68% for BOD_5, 62-88% for Total Phosphorous, 77-100% for Total Kjeldahl Nitrogen, and 60-100% for Nitrite, 14-94% for Fecal Coliforms and 90-100% for Total Suspended Solids.
- The removal efficiency generally increases with increased clay content of soils.
- The final effluent quality is more dependent on COD loading than Clay content or swell-shrinkage.
- Greater confidence can be gained in treated effluent sampling through the long-term deployment of gravity fed lysimeters.

Recommendations

1) Removal efficiencies can be improved by adding pretreatment filters to the existing treatment system. An example of a system providing enhanced pretreatment employs a modified recirculating sand filter concept and produces an effluent with BOD_5 and TSS concentrations typically below 10mg/L. The rate of reduction observed was generally in the range of 60% to 90%. Effluent fecal coliform levels were mostly in the range of 103-104 CFU/100 mL, which is a 2-5 log reduction (99%-99.999% reduction) from levels typically observed in septic tank effluent (Venhuizen 1995).

2) A percolation test, which was the method used to evaluate soil type for most sites studied, should be done accurately for each site. Hydraulic conductivity should not be the sole criteria for design. Fluctuations in ground water level due to seasonal variations must be considered in the design phase. Most importantly, groundwater levels during the wet season should be used for design purposes.

3) Estimation of hydraulic loading rate should be based on climatic conditions.

4) All existing systems should be inspected for adequate installation and operation every 4– 5 years.

5) Many of the problems associated with the maintenance phase are due to the improper use of septic systems. Educating homeowners on proper maintenance of the septic system reduces incidental pollution and helps to implement pollution control strategies.

6) State and local governments should develop a regular inspection program, which includes monitoring of the effluent.

7) Texas administrative code, Section 30 Texas Administrative Code, Chapter 285 pertaining to on-site sewage facilities (OSSF) should be reviewed to define failure of systems based on system performance rather than design parameters such as loading rate. Some states (e.g. State of Wisconsin's Administrative Code, commonly referred to as "NR 140") sets limits for many substances that may pollute groundwater (WAC 1985).

8) On Site Sewage Facilities should be evaluated over periods of time spanning various climatic conditions.

Appendix. Raw Data

Sample retention periods for specific analytes, such as BOD, were exceeded in some cases during the intense sampling campaign. The Standard Methods for the Examination of Water and Wastewater (19^{th} edition, 1995) recommends a maximum holding time of 24 hours while in cold storage. These analytes were sacrificed in order to ensure that representative samples from all of the 18 sites were collected within the project time frame. These, and other data failing internal quality assurance standards were eliminated from this report.

Field Observations

Field observations for each of the sites studied are listed in Table 6

• Table 6 Summary of Field Observations

Site ID	Date visited	Method of Extraction	Field Notes
1	6/21/99	Hand-held pump	The first day we arrived in Orange County it had rained profusely at our first site. Problems with hand pump, no visible stagnant water. Used site source water to prepare silica mix.
2	6/21/99	Hand-held pump	Rained severely the day before. It should be noted that the owners have had a problem with clogged filters within the system. Problems with hand pump, no visible stagnant water. Used site source water to prepare silica mix.
3	6/22/99	Hand-held pump	It should be noted that there is stagnant water around the system and it has begun to rain. Problems with hand pump. Used site source water to prepare silica mix.
4	6/23/99	Hand-held pump	Rainy day. Problems with hand pump, no visible stagnant water. Used site source water to prepare silica mix.
5	6/30/99	Mechanical pump	Sunny Day, no visible stagnant water. Used site source water to prepare silica mix.
6	6/31/99	Mechanical pump	Property located in Wildwood, no visible stagnant water. Used site source water to prepare silica mix.
7	7/1/99	Mechanical pump	Sunny day, no visible stagnant water. Used site source water to prepare silica mix.
8	7/23/99	Mechanical pump	Note creek on property. Used site source water to prepare silica mix.
9	7/20/99	Mechanical pump	Rained while doing extraction. Used site source water to prepare silica mix.
10	7/21/99	Mechanical pump	Cloudy day, note ponds on property (1 foot depth). No visible stagnant water. Used site source water to prepare silica mix.
11	7/22/99	Mechanical pump	Cloudy day, no visible stagnant water. Used site source water to prepare silica mix.
12	7/22/99	Mechanical pump	Sunny day, no visible stagnant water. Used site source water to prepare silica mix.
13	7/22/99	Mechanical pump	Sunny day, no visible stagnant water. Used site source water to prepare silica mix.
14	7/23/99	Mechanical pump	Sunny day, no visible stagnant water. Used site source water to prepare silica mix.
15	8/21/99	Mechanical pump	Rainy day with visible stagnant water. Note pond located on property. Used site source water to prepare silica mix.
16	8/21/99	Mechanical pump	Rainy day but no visible stagnant water. Used site source water to prepare silica mix.
17	8/21/99	Mechanical pump	Rainy day but no visible stagnant water. Used site source water to prepare silica mix.
18	8/22/99	Mechanical pump	Note creek on property, used source water to prepare silica mix. No visible stagnant water.

Soil Characteristization

• Table 7. Summary of Soil Texture at 1ft Depth.

Site ID	% Sand	% Silt + Clay	% Clay
1	45.0	55.0	40.0
2	42.5	57.5	30.0
3	85.0	15.0	7.5
4	62.5	37.5	15.0
5	80.0	20.0	10.0
6	92.5	7.5	2.5
7	80.0	20.0	7.5
8	70.0	30.0	20.0
9	80.0	20.0	13.0
10	85.0	15.0	5.0
11	82.5	17.5	7.5
12	82.5	17.5	5.0
13	92.5	7.5	5.0
14	75.0	25.0	5.0
15	87.5	12.5	5.0
16	85.0	15.0	5.0
17	82.5	17.5	5.0
18	70.0	30.0	30.0

• Table 8. Summary of Soil Texture at 2ft Depth.

Site ID	% Sand	% Silt + Clay	% Clay
1	65.0	35.0	7.5
2	40.0	60.0	27.5
3	65.0	35.0	12.5
4	52.5	47.5	12.5
5	82.5	17.5	7.5
6	85.0	15.0	5.0
7	82.5	17.5	7.5
8	47.5	52.5	35.0
9	70.0	30.0	17.5
10	85.0	15.0	8.8
11	65.0	35.0	7.5
12	75.0	25.0	12.5
13	82.5	17.5	10.0
14	75.0	25.0	12.5
15	87.5	12.5	5.0
16	80.0	20.0	10.0
17	80.0	20.0	10.0
18	50.0	50.0	37.5

• Table 9. Summary of Soil Texture at 3ft Depth.

Site ID	% Sand	% Silt + Clay	% Clay
1	67.5	32.5	7.5.0
2	60.0	40.0	12.5
3	32.5	67.5	45.0
4	60.0	40.0	25.0
5	75.0	25.0	5.0
6	90.0	10.0	5.0
7	85.0	15.0	7.5
8	55.0	45.0	35.0
9	60.0	40.0	17.5
10	70.0	30.0	12.5
11	60.0	40.0	12.5
12	82.5	17.5	7.5
13	60.0	40.0	20.0

Site ID	% Sand	% Silt + Clay	% Clay
14	62.5	37.5	20.0
15	85.0	15.0	7.5
16	72.5	27.5	12.5
17	72.5	27.5	12.5
18	50.0	50.0	42.5

- Table 10. Summary of Soil Moisture (%) at Depth.

Site ID	1ft	2ft	3ft
1	85.2	85.7	87.0
2	82.2	76.2	79.3
3	76.7	82.9	74.5
4	80.2	83.4	75.7
5			
6	90.7	90.7	88.2
7	90.4	93.7	94.3
8	87.1	77.0	76.3
9	77.0	78.8	81.9
10	82.6	82.6	81.2
11	76.2	85.5	85.5
12	93.7	95.3	95.2
13	89.7	91.2	88.2
14	87.3	85.8	85.0
15	97.7	98.0	96.5
16	85.5	86.3	83.7
17	83.4	85.7	84.7
18	80.6	75.8	74.3

- Table 11. Summary of Soil Type, Clay Content, Swell & Hydraulic Conductivity.

Site ID	Soil Type*	Clay Content %	Swell %	Hydraulic Cond.
1	SL	7.5	3.8	22
2	SL	20.0	10.4	2
3	C	28.8	11.2	22
4	SCL	18.8	7.2	12
5	SCL	6.3	3.4	2
6	SILT	5.0	2.4	2
7	LS	7.5	3.8	2
8	SCL	35.0	10.0	2
9	SL	17.5	6.8	2
10	SL	10.6	4.7	2
11	LS	10.0	8.3	2
12	LS	10.0	4.6	2
13	SCL	15.0	6.1	2
14	SCL	16.3	6.5	2
15	LS	6.3	1.4	2
16	LS	11.3	6.7	2
17	LS	11.3	0.2	2
18	SC	40.0	11.4	22

*SL-Sandy loam, C-Clay, SC-Sandy Clay, SCL-Sany Clay Loam, L-Loam & LS-Loamy Sand

pH

- Table 12. Summary of Effluent pH Measurements.

Site ID	PH raw	pH treated
1	7.0	7.1
2	6.9	6.8
3	6.6	6.7
4	7.0	7.2
5	6.2	6.7

Site ID	PH raw	pH treated
6	6.7	6.8
7	6.3	7.5
8	7.1	7.3
9	6.6	7.0
10	7.0	7.5
11	7.0	6.8
12	6.8	7.2
13	7.0	7.8
14	6.9	6.8
15	7.2	7.1
16	6.7	6.6
17	7.2	7.0
18	6.9	6.8

Chemical Oxygen Demand

• Table 13. Summary of Effluent Chemical Oxygen Demand (mg/L) Analyses.

Site ID	COD raw_1	COD raw_2	COD $raw_{Avg.}$	COD $treated_1$	COD $treated_2$	COD $treated_{Avg.}$	Removal Efficiency %
1	54.0	104.0	79.0	38.0	32.0	35.0	55.7
2	76.0	74.0	75.0	45.0	43.0	44.0	41.3
3	61.0	61.0	61.0	28.0	24.0	26.0	57.4
4	88.0	63.0	75.5	38.0	32.0	35.0	53.6
5	160.0	165.0	162.5	60.0	64.0	62.0	61.9
6	97.0	96.0	96.5	46.0	47.0	46.5	51.8
7	106.0	134.0	120.0	32.0	30.0	31.0	74.2
8	134.0	120.0	127.0	95.0	70.0	82.5	35.0
9	38.0	33.0	35.5	9.0	8.0	8.5	76.1
10	17.0	18.0	17.5	14.0	13.0	13.5	22.9
11	35.0	56.0	45.5	12.0	30.0	21.0	53.9
12	—	45.0	45.0	22.0	18.0	20.0	55.6
13	91.0	—	91.0	63.0	62.0	62.5	31.3
14	31.0	—	31.0	14.0	18.0	16.0	48.4
15	20.0	—	20.0	—	9.0	9.0	55.0
16	14.0	—	14.0	—	3.0	3.0	78.6
17	14.0	—	14.0	—	5.0	5.0	64.3
18	18.0	—	18.0	—	6.0	6.0	66.7

Biochemical Oxygen Demand

• Table 14. Summary of Effluent Biochemical Oxygen Demand (mg/L) Analyses.

Site ID	DO raw 1	DO raw 2	BOD raw (meas.)	BOD raw/ COD raw	BOD raw (est.)	DO treat ed 1	DO treat ed 2	BOD treated (meas.)	BOD treated/ COD treated	BOD treated (est.)	BOD eff. (meas)	BOD eff. (est)
1	7.9	7.9	0.0	0.0	31.4	7.2	5.7	18.0	0.5	21.5	–	0.3
2	8.5	5.9	31.2	0.4	29.8	8.4	6.8	19.2	0.4	27.0	0.4	0.1
3	9.4	8.9	6.0	0.1	24.3	9.1	6.8	27.6	1.1	16.0	-3.6	0.3
4	10.0	.10	118.8	1.6	30.0	8.8	4.1	56.4	1.6	21.5	0.5	0.3
5	8.9	8.3	7.8	0.0	64.6	9.0	8.8	2.4	0.0	38.1	0.7	0.4
6	9.0	8.4	7.2	0.1	38.4	8.0	3.7	51.6	1.1	28.6	-6.2	0.3
7	9.1	2.3	81.6	0.7	47.7	9.2	7.0	26.4	0.9	19.0	0.7	0.6
8	9.0	7.1	22.8	0.2	50.5	9.1	8.5	7.2	0.1	50.7	0.7	0.0
9	8.9	8.5	4.8	0.1	14.1	8.9	8.5	4.8	0.6	5.2	0.0	0.6
10	9.0	7.9	13.2	0.8	7.0	9.0	4.3	56.4	4.2	8.3	-3.3	-0.2
11	9.0	6.2	33.6	0.7	18.1	9.0	8.0	12.0	0.6	12.9	0.6	0.3
12	5.6	2.3	39.6	0.9	17.9	8.2	6.8	16.8	0.8	12.3	0.6	0.3
13	8.0	4.1	46.8	0.5	36.2	7.1	4.8	27.6	0.4	38.4	0.4	-0.1
14	7.6	6.1	18.0	0.6	12.3	8.8	7.6	14.4	0.9	9.8	0.2	0.2
15	7.5	4.8	32.4	1.6	8.0	7.4	6.7	8.4	0.9	5.5	0.7	0.3
16	8.1	7.9	2.4	0.2	5.6	8.2	7.6	7.2	2.4	1.8	-2.0	0.7
17	7.6	7.1	6.0	0.4	5.6	7.4	7.0	4.8	1	3.1	0.2	0.4
18	7.8	7.4	4.8	0.3	7.2	7.9	6.7	14.4	2.4	3.7	-2.0	0.5

Highlighted values indicate inconsistent data. For Site 1, no net change in the DO measurements for the {BOD raw} sample was detected, resulting in a measured BOD in of 0.0 mg/L. Sites 4 & 15 both resulted in {BOD raw / COD raw} ratios greater than 1.0. An average {BOD raw / COD raw} ratio of 0.4 was estimated from samples excluding Sites 1, 4 and 15. This ratio was used to calculate the {BOD raw (est.)} column from the COD raw values in Table 13. Measured {BOD treated} values Sites 3, 4, 6, 10, 16, 17 and 18 exceeded COD measurements and were therefore discounted in the estimation of the average {BOD treated / COD treated}. An average {BOD treated / COD treated} ratio of 0.6 was used to calculate {BOD treated (est.)} values from the COD out values in in Table 13. Estimated BOD removal efficiencies at Sites 10 and 13, yielded negative results and were not included in the calculation of the average estimated BOD removal efficiency.

Phosphorous

• Table 15. Summary of Phosphorus (mg/L) Analytical Results.

Site ID	Phos raw1	Phos raw2	Phos rawAvg.	Phos treated1	Phos treated2	Phos treatedAvg.	Removal Efficiency %
1	3.3	3.1	3.2	0.7	0.6	0.7	79.4
2	4.1	3.9	4.0	1.0	0.7	0.8	80.0
3	3.9	4.1	4.0	0.7	0.6	0.7	83.6
4	4.6	4.5	4.6	1.0	0.9	0.9	79.8
5	4.6	3.5	4.1	1.0	0.5	0.7	82.6
6	5.5	0.1	2.8	0.8	0.3	0.6	80.4
7	4.4	4.9	4.7	0.7	0.8	0.8	83.7
8	5.5	4.7	5.1	0.5	1.0	0.7	85.9
9	2.8	2.	2.5	0.3	0.3	0.3	87.8
10	3.1	2.9	3.0	0.8	0.7	0.8	75.0
11	4.4	4.2	4.3	0.6	0.6	0.6	86.0
12	5.5	4.6	5.1	1.8	1.9	1.9	63.4
13	6.8	6.9	6.9	0.9	0.8	0.8	87.7
14	2.6	2.9	2.8	0.6	0.7	0.5	81.1
15	4.9	—	4.9	0.8	—	0.8	83.1
16	5.1	—	5.1	0.7	—	0.7	86.0
17	—	2.8	2.8	—	0.6	0.6	80.4
18	4.7	—	4.7	0.8	0.8	0.8	83.7

Total Kjeldahl Nitrogen

• Table 16. Summary of Total Kjeldahl Nitrogen (mg/L) Analytical Results.

Site ID	TKN raw	TKN treated	Removal Efficiency %
1	14.9	1.2	92
2	12.1	1.1	91
3	10.0	0.0	100
4	19.0	0.5	97
5	11.0	0.0	100
6	16.9	1.7	90
7	21.9	1.1	95
8	13.0	1.3	90
9	6.3	0.0	100
10	12.0	1.2	90
11	12.5	1.3	90
12	16.3	1.6	90
13	19.8	2.0	90
14	13.9	1.4	90
15	11.2	2.6	77
16			

Site ID	TKN raw	TKN treated	Removal Efficiency %
17			
18			

Nitrite

• Table 17. Summary of Nitrite Analytical Results.

Site ID	NO2 raw1	NO2 raw2	NO2 rawAvg	NO2 treated1	NO2 treated2	NO2 treatedAvg	NO2 Eff%
1	0.33	0.33	0.33	0.01	—	0.01	97.9
2	0.04	0.04	0.04	0.00	—	0.00	97.6
3	0.05	0.07	0.06	0.00	—	0.00	95.1
4	0.31	0.30	0.31	0.01	—	0.01	95.4
5	0.07	0.05	0.06	0.00	0.01	0.00	94.2
6	0.05	0.04	0.04	0.00	0.01	0.00	89.9
7	0.06	0.05	0.06	0.01	0.01	0.01	84.5
8	0.06	0.05	0.05	0.02	0.02	0.02	67.0
9	0.08	0.07	0.07	0.00	—	0.00	98.6
10	17.00	18.00	17.50	28.00	25.00	26.50	-51.4
11	35.00	56.00	45.50	94.00	84.00	89.00	-95.6
12	—	—	—	149.00	165.00	157.00	—
13	91.00	—	91.00	63.00	62.00	62.50	99.3
14	31.0	—	31.0	93.00	99.00	96.00	96.9
15	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—

Nitrite data from Sites 10-14 demonstrated values dramatically inconsistent with Sites 1-9 and orders of magnitude greater than the generally accepted range. These Sites were not included in the Nitrite analysis. Nitrite analysis was discontinued for Sites 16-18.

Fecal Coliforms

• Table 18. Summary of Fecal Coliform Analytical Results (MPN/100mL).

Site ID	Fecal raw	Fecal treated	Removal Efficiency%
1	16	6	62.50
2	14	8	42.9
3	28	16	42.9
4	—	—	—
5	14	9	35.7
6	16	7	56.3
7	30	10	66.7
8	16	1	93.8
9	7	6	14.3
10	38	17	55.3
11	54	36	33.3
12	11	6	45.5
13	20	8	60.0
14	38	4	89.5
15	—	—	—
16	—	—	—
17	—	—	—
18	—	—	—

Total Suspended Solids

• Table 19. Summary of Total Suspended Solids Analytical Results (mg/L).

Site ID	TSS Raw1	TSS Raw2	TSS rawavg	TSS treated1	TSS treated2	TSS treatedavg	Removal Efficiency %
1	31.90	33.3	32.60	4.3	2.1	3.2	90.2
2	32.68	26.72	29.70	1.6	2.2	1.9	93.6
3	19.26	26.94	23.10	0.9	0.9	0.9	96.1
4	28.36	33.64	31.00	1.9	0.7	1.3	95.8
5	51.30	67.9	59.60	5.6	4.2	4.9	91.8
6	9.63	14.41	12.02	0.9	0.3	0.6	95.0
7	59.60	67.6	63.60	4.9	3.5	4.2	93.4
8	38.40	60.2	49.30	2.8	1.4	2.1	95.7
9	18.50	14.1	16.30	1.0	0.2	0.6	96.3
10	11.60	9.4	10.50	0.1	0.0	0.0	100.0
11	NA	21	21.00	NA	1.6	1.6	92.4
12	17.90	19.3	18.60	1.5	0.9	1.2	93.5
13	29.60	39.6	34.60	0.0	0.0	0.0	100.0
14	16.50	12.1	14.30	0.9	1.7	1.3	90.9
15	5.90	5.3	5.60	11.2	8.4	9.8	–
16							
17							
18							

Appendix. References

American Society for Testing and Materials. (1994). 1994 Annual Book of ASTM Standards. Philadelphia, Astm.

APHA (1995). Standard Methods for the Examination of Water and Wastewater, American Public Health Association.

Aravena, R., M. L. Evans, et al. (1993). "Stable Isotopes of Oxygen and Nitrogen in Source Identification of Nitrate from Septic Tanks." Ground Water(31): 180-186.

Bastians, R. K. and D. A. Hammer (1993). The use of Constructed Wetlands for Wastewater treatment and Recycling. Constructed Wetlands for Water Quality Improvements. Boca Raton, FL, CRC Press: 59-68.

Bicki, T. J. and R. B. Brown (1985). On-Site sewage disposal - Wastewater flow and quality. Notes in Soil Science No 19. Gainesville, FL, Soil Science Department, G-159 McCarty Hall, Institute of Food and Agricultural Sciences, University of Florida.

Canter, L. W. and R. C. Knox (1985). Septic Tank System Effects on Ground Water Quality, Lewis Publishers, Inc.

Crites, R. and G. Tchobanoglous (1998). Small and Decentralized Wastewater Management Systems. New York, McGraw-Hill.

EPA (1986). Septic Systems and Ground-Water Protection: An Executive's Guide. Washington D.C., Office of Ground-Water Protection, U.S. Environmental Protection Agency.

EPA (1998). Guidance for Prospective Ground-Water Monitoring Studies. Washington D.C., U.S. Environmental Protection Agency.

Frankenberger, J., W.T (1988). Chapter 14. Fate of Wastewater Constituents in Soil and Groundwater: Pathogens. Irrigation with Reclaimed Municipal Wastewater - A

Guidance Manual. G. S. Pettygrove and T. Asano, Lewis Publishers, Inc.

GEOFLOW Inc. Installation Detail, , Subsurface Irrigation.

Gerba, C. P. and S. M. Goyal (1985). Chapter 9. Pathogen Removal from Wastewater during Groundwater Recharge. Artificial Recharge of Groundwater. T. Asano, Butterworth Publishers: 283-317.

Gordon, D. G. (1989). Managing Nonpoint Pollution: An Action Plan Handbook for Puget Sound Watershed. Seattle, WA, Puget sound Water Quality Authority.

Hagedorn, C., E. L. McCoy, et al. (1981). "The Potential for Ground Water Contamination from Septic Effluents." Journal of Environmental Quality **10**(1): 1-8.

Hammer, D. A. (1989). Constructed Wetlands for Wastewater Treatment: Municipal Industrial and Agricultural. Chelsea, MI, Lewis Publishers.

Hudspeth, W. H. Tank Installation Detail. 18414 Burkhardt, Tomball, Texas 77375.

IUP (1990). 1990 Census of Population and Housing, University of Texas Urban Issues Program.

Jacquez, R. B., F. Vora, et al. (1991). Onsite Treatment of Septic-Tank Effluent by a Rotating Biological Contractor. Sixth National Symposium on Individual and Small Community Sewage Systems, Michigan, ASAE.

Jarrett, D. D. Fritton, et al. (1985). "Renovation of Failing Absorption Fields by Water Conservation and Resting." American Association of Agricultural Engineers **85 - 2630**.

Keswick, B. H. and C. P. Gerba (1980). "Viruses in Ground Water." Environmental Science and Technology **14**(II): 1290-1297.

Laak, R. (1982). On-Site Soil Systems, Nitrogen Removal. Alternative Wastewater Treatment. A. S. Eikum and R. W. Seabloom, D. Reidel Publishing Co.: 129-143.

Mancl, K. and K. Young. (1997). Giardiasis. Agricultural Engineering Fact Sheet. SW-22., The Pennsylvania State University, College of Agriculture, Cooperative Extension Service.\.

Metcalf & Eddy, I. (1995). Wastewater Engineering: Treatment, Disposal and Reuse. New York, McGraw-Hill.

Naismith Engineering, I. (1990). Corpus Christi Natural Estuary Program Study of Onsite Sewage Facilities. Corpus Christi, Corpus Christi Bay National Estuary Program.

Page, A. L., R. H. Miller, et al. (1982). Methods of soil analysis. Madison, Wis., American Society of Agronomy : Soil Science Society of America.

Pavandan, K. (2000). Evaluation of Existing Subsurface Drip Irrigation Systems in Texas Coastal Plains. Environmental Engineering. Kingsville, Texas A&M University - Kingsville.

Perkins, R. J. (1989). New Mexico Environmental Improvement Agency Santa Fe. Chelsea, MI, Lewis Publishers, Inc.

Petrovic, A. M. (1990). "The Fate of Nitrogenous Fertilizers Applied to Turfgrass." Journal of Environmental Quality **19**(2): 1-14.

Reneau, R. B., Jr., C. Hagedorn, et al. (1989). "Fate and Transport of Biological and Inorganic Contaminants from On-Site Disposal of Domestic Wastewater." Journal of Environmental Quality **18**(2): 135-144.

SME Corp. (1991). Model 2800 Guelph Permeameter. P.O Box San Barbara, CA 93105, USA., Soil Moisture Equipment Corp.

SME Corp. (1999). Model 1900 Soil Water Sampler. P.O Box San Barbara, CA 93105, USA., Soil Moisture Equipment Corp.

Stat Soft (1998). Statisca 5.1, '98 Edition. Tulsa, OK 74104, Stat Soft 2300 East 14th Street.

TAC (1997). Texas Administrative Code 30 Environmental Quality chapter 285 On-Site Sewage Facilities.

Tayler, C., J. Yahner, et al. (1997). An Evaluation of On-Site Technology in Indiana, Purdue University, Agronomy and Agricultural and Biological Engineering.

Tyler, E. J., R. Laak, et al. (1977). The Soil as a Treatment System. Second National Home Sewage Treatment Symposium, American Society of Agricultural Engineers.

Venhuizen, D. (1995). An Analysis of the Potential Impacts on Groundwater Quality of On-Site Wastewater Management Using Alternative Management Practices.

WAC (1985). Groundwater Quality. Chapter NR 140, Wisconsin Administrative Code.

Wilson, N. (1995). Soi Water and Groundwater Sampling. Boca Raton, CRC Lewis.